DEPARTMENT OF THE ARMY
US ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
PICATINNY ARSENAL, NEW JERSEY 07806-5000

AMSRD-AAR-AEP-F **August 8, 2005**

MEMORANDUM FOR: AMSRD-AAR-AEW-A(D), Attn: Mr. Stanley D. Kahn

SUBJECT: ARDEC Position Paper on the DoD Mandated Electronic Product Code (EPC) Global Radio Frequency Identification (RFID) Technology for Ammunition Logistic Applications.

1. References:

(a) Department Of Defense Interface Standard, **Subject:** MIL-STD-464A Electromagnetic Environmental Effects Requirements For Systems, dated 19 December 2002.

(b) Department of Defense Software, **Subject:** Maximum Allowable Environment (MAE) Analysis Program, dated 1 August 2001.

(c) Department of the Army Pamphlet 385–64, **Subject:** Ammunition and Explosives Safety Standards, dated 15 December 1999.

2. RFID Background: The Department of Defense has announced the establishment of a Radio Frequency Identification (RFID) policy which will greatly improve the management of munitions inventory by providing hands-off processing, improved data quality, item management, asset visibility and maintenance of materiel.

This technology equipment utilizes inexpensive passive (with no battery) tags for labeling of DoD materiel. The information on the tags will be read and or modified using a hand-held reader which is designed to emit RF energy at various frequencies and power levels. The tags don't generate RF energy, they just reflect this energy from the reader. However, most RFID reader units will be operating in the 850 MHz - 950 MHz frequency band. Fixed readers are designed to radiate up to 4 watts EIRP, while the hand-held readers radiate up to 1 watt EIRP. The typical reliable reading range of a 4 watt reader is about 4 feet or less.

4. Objectives: Provide a less conservative, but Safe Separation Distance (SSD) value for bare munition items (outside their shipping container) and inside their shipping containers.

5. EID Safety Criteria: Since the early 90s, the biggest safety issue for the implementation of RFID technology, for ammunition logistics, was the concern of Radio Frequency (RF) sensitive munitions in their storage, shipping and bare (i.e outside their shipping container) configurations. An RF susceptible munition is one that utilizes an RF susceptible Electro-Initiated Device (EID) as its primary initiation train to detonate an in-line High Explosive or initiate a rocket motor. The EID's pass/fair characteristic against RF energy is defined by ref 1(a) *...the maximum allowable induced level for electrically initiated devices (EIDs) in required environments is 15% of the maximum no-fire current.* For the most sensitive IED (i.e the M100 micro-det), having a 85 mA NFC, the 15 % value is 12.7 mA which will be used later in the evaluation. See Enclosure 1

6. RFID Safety Issues: For the past 10 years, in order to address any RF safety issues, the DoD has developed a series of strategies to remedy the susceptibility of these items and some of the efforts accomplished by the Tri-Services are presented below.

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6.1 Joint Spectrum Center (JSC):

The JSC formed the JOCG Tri-Service Hazards of Radiation to Ordnance (HERO) subcommittee to make sure Project Managers and Weapon developers design and evaluate weapon systems to survive harsh Radio Frequency (RF) environments in all of their life cycle configurations. Some of the efforts accomplished by the HERO committee, in support of RFID technology, are presented below.

(a) Maximum Allowable Environment (MAE) Software: Developed a Windows based program to conservatively calculate the far-field Safe Separation Distance (SSD) for ordnances against high powered communications and radar systems.

(b) Joint Spectrum Center Ordnance E3 Risk Assessment Database (JOERAD): Developed another Windows based database program to store the RF susceptibility data of all DoD weapon systems as a function of their DODICs, NSNs and Nomenclature**.** Most RF susceptibility submissions have to show that these items have to be safe in their storage, shipping, handling and pre-deployment configurations.

6.2 Army Boards:

Acquisition regulations require that new weapon systems must meet their required safety and operational requirements. Therefore, before the weapon is allowed to be fielded, it has to go through a number of safety boards where their members scrutinize the design for safety and for reliability. Several Army organizations at Picatinny and at other facilities ensure that HERO requirements are enforced. The Navy and Air force have similar organizations that accomplished the same goal. These Army organizations are listed below along with their responsibilities:

(a) ARDEC E3 Requirements Board: This local board ensures PMs and Weapon Developers design and evaluate their weapon systems to meet HERO and other electromagnetic requirements in their shipping, storage, handling, pre-deployment and post-deployment configurations.

(b) Army Fuse Safety Board: This Army board ensures all PMs and Weapon Developers design and evaluate weapon systems that utilize Safe and Arm (S&A) and Fuzing mechanism to meet HERO and other electromagnetic requirements in their shipping, storage, handling and pre-deployment configurations only.

(c) ARDEC Systems Safety Board: This local organization ensures that all weapons systems are safe in their shipping, storage, handling, pre-deployment and post-deployment configurations.

(d) US Army Technical Center for Explosives Safety (USATCES): This Army organization ensures all Army facilities perform shipping, storage, demilitarization and handling operations of weapon systems are performed safe. USATCES is responsible for PAM 385-64.

(e) ARDEC Materiel Release (MR) Board: This local board ensures PMs and Weapon Developers field weapons systems that meet all safety and operational requirements.

6.3 New Technologies:

In order to increase the safety of Army weapon systems, innovative technologies have been developed and implemented by ARDEC by replacing existing RF sensitive EIDs with high energy or insensitive technologies such as Exploding Foil Initiators (EFI), laser primers, shock tube initiators and 1 amp / 1 watt devices. Artillery and smart/precision weapon designs have been improved by incorporating out-of-line S&As in their fuzing systems to prevent EIDs from initiating high explosives. In addition, Packaging engineers have improved all shipping containers to address RF environments by making sure the munition items are stored inside steel containers, aluminum barrier bags, conductive polymers, etc.

7. RFID Safety Evaluations:

The US Army utilizes one of the lowest energy EIDs in legacy and modern ordnance systems. The RF susceptibility characteristic of an ordnance is a function of its shielding, the EID's No-Fire Current level, the distance from the transmitter, the transmitter's operating frequency and the transmitter output power. In this case, the transmitter is either the hand-held or fixed reader. All theoretical and empirical evaluations will be performed at 902 MHz which is the midpoint between 850-950 MHz.

7.1 RFID Theoretical Evaluations:

The following evaluation was performed by utilizing an approved Windows based software that calculates the SSD value in the far field region only. The software has been programmed to assume that the EID is outside its metallic shipping container, its NFC value is 85 mA, its bridgewire resistance is 7 ohms, the EID is tuned to the resonance frequency of the RFID reader and its RF power received is totally matched across its bridgewire. The SSD value includes a mandated safety factor of 16.5 dBs or 7:1.

Results: Both SSD values for a bare or RF susceptible EID were calculated to be 3 meters (9 feet), regardless of the output power. See Enclosure 2. The MAE program at 902 MHz is too conservative because it has a built in limitation of 3 meters to prevent the user from computing SSD values inside the near field region (or unstable/non-linear region). Ironically, for 902 MHz, the near/far field region falls within 6 feet. Therefore, direct RF measurements must be performed to obtain a less conservative SSD value.

7.2 RFID Measurements:

In order to measure accurate SSD values, RF measurements were performed using an instrumented EID. Enclosure 3a shows how this evaluation was performed. Basically, a simulated RFID reader as well as a simulated M100 detonator were used.

Two precision and calibrated dipole antennas were used to accomplish the transmission and reception of RF. The lengths of the custom made antenna leads were cut, based on the resonance frequency generated by the transmitter. For 902 MHz, the total lengths were 6". The total output power, before the antenna, was set to 2.5 watts, since the antenna already comes with a 1.6 gain, the total output power became 4 watts.

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7. RF Evaluations: (Continued)

The induced RF currents across the simulated M100 bridgewire were measured by a spectrum analyzer as a function of distance. The output impedance of the M100 dipole antenna is set by the antenna company to 50 ohms. The input of the spectrum analyzer is also designed to accept a 50 ohm antenna to transmit maximum power without reflections. Once the 50 ohm measurements were made, the measurements were converted to 7 ohms, by using an equation in Enclosure 3a. Finally, the distance between the simulated RFID reader and the M100 was adjusted and measurements collected. The calculated data, based on measured data, was plotted in Enclosure 3b.

Results: For a bare or RF susceptible EID, the SSD value was measured to be 12" or 1 foot.

7.3 Live Fire Evaluations:

In addition to theoretical and RF measurements, live fire evaluations on live M100 detonators were performed to determine how much RF power as a function of distance is required to fire such device. Enclosure 5a shows how the evaluation was set up. Enclosure 5b shows how the procedures were followed. The test data was tabulated in Enclosure 4c and plotted in Enclosure 5d.

Results: For a bare EID, the SSD value was measured to be 10 inches or just less than 1 foot. However, the SSD value of 0 inches was achieved, if the antenna leads are removed. Leads are never attached to the M100 during its storage and shipping configurations. These results support the measured values.

8. Recommendations:

As mentioned in paragraph (6), the Army has put together an aggressive accountability, design and evaluation program with the objective of ensuring all Army weapon systems are safe against RF during their storage, shipping, handling and deployment configurations. Based on the evaluations is paragraphs 7.1, 7.2 and 7.3 the following recommendations are offered:

(a) Bare munitions (outside their shipping containers), RF susceptible munitions or foreign munitions should require a 1 foot SSD from a 900 +/- 50 MHz, 4 watt reader. **Reason:** This is the worst case configuration.

(b) HERO certified bare munitions require no SSD. **Reason:** These items have been exposed to high field levels that are way above the fields generated by a 4 watt signal at 1 foot away. See Enclosure 8.

(c) Munitions shipped inside metallic containers require no SSD. **Reason:** Metallic shipping containers are the best way to shield a 900 +/- 50 MHz, 4 watt reader from bare or RF sensitive munitions.

(c) RFID readers should not be used when Army munitions are being shipped by Aircrafts or Navy ships. **Reason:** The RFID transmitter may interfere with the aircraft's communication radios and navigation aids. On a Navy ship, its powerful transmitters my interfere with either the reader or tag.

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8. Recommendations: (Continued)

(d) RFID readers should only be allowed to radiate a maximum of 4 watts EIRP, when interrogating RFID passive tags. **Reason:** The authorization is for 4 watts, maximum. The contractor shall ensure that the output of the transmitter is not controlled by software or use programmable attenuators which could cause the transmitter to generate above 4 watts. The contractor shall submit a DD Form 1494 stating the transmitters operating specifications.

(e) If the contents inside a shipping container are unknown, such as foreign munitions or munitions that are coming back from the battlefield (unknown status), these items should be stored inside a metallic shipping container or the RFID reader should be kept 1 foot away or greater from the shipping container.

(f) Multiple RFID Readers can be used at a fixed location, but they have to transmit their signals one at a time. **Reason:** The combine field intensity could increase proportionally, when two or more 4 watt signals are generated at the same time.

Note: In Enclosure 6, a list of Army legacy systems have been listed and classified as HERO susceptible ordnances in their tactical configurations. However, no safety issues have been reported exposing these systems to RF in their shipping and storage configurations because they are properly protected by their shipping container or packaging material. Based on the HERO reports, they are not RF susceptible outside their shipping containers at 900 MHz +/- 50 MHz. Enclosure 7 lists all fielded ARDEC munition items that contain M100 low energy micro-detonators that have been RF qualified per MIL-STD-464A.

10. Point of contact for this office is the undersigned, DSN 880-4667<dgutierr@pica.rmy.mil>.

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ENCL: as

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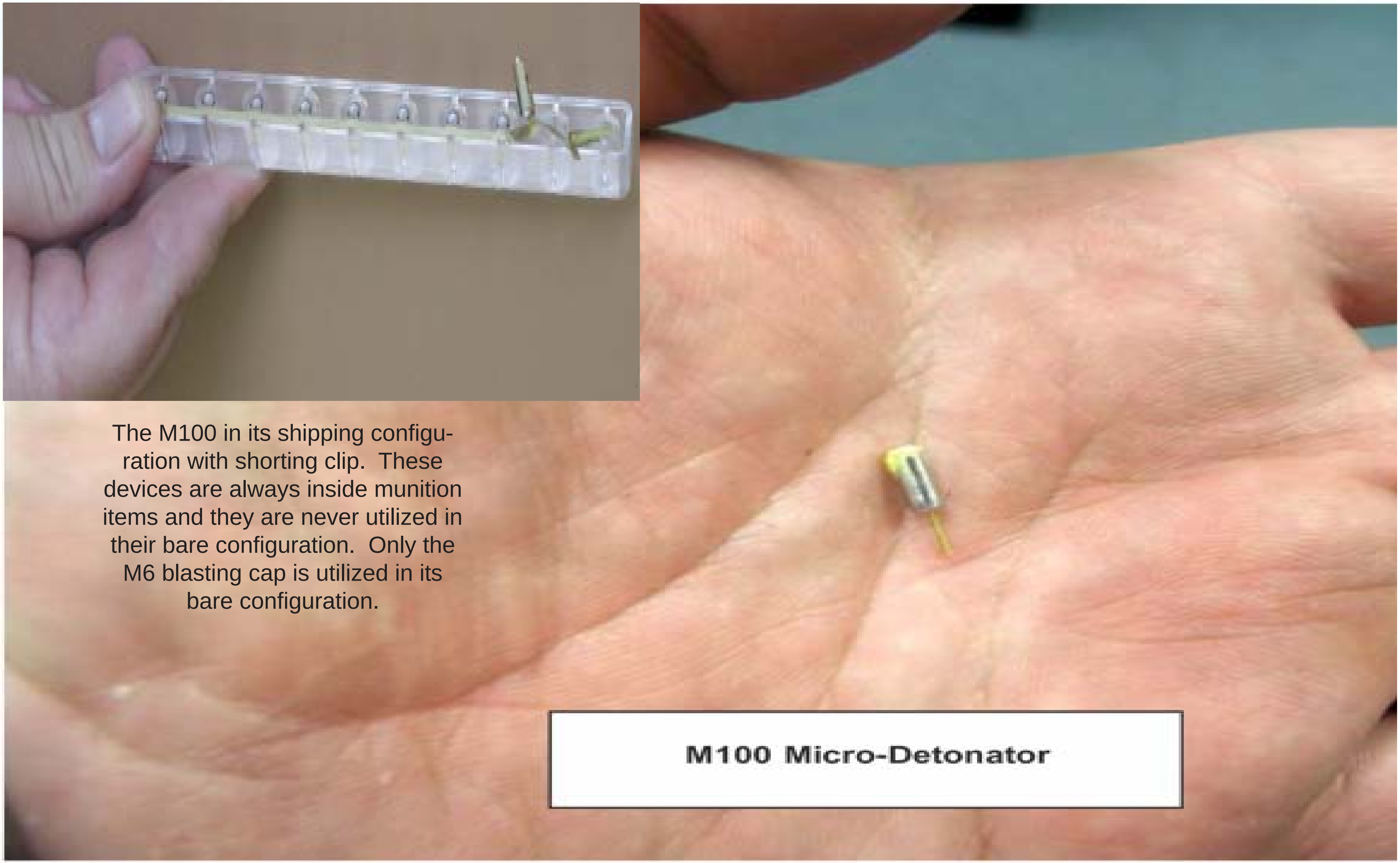
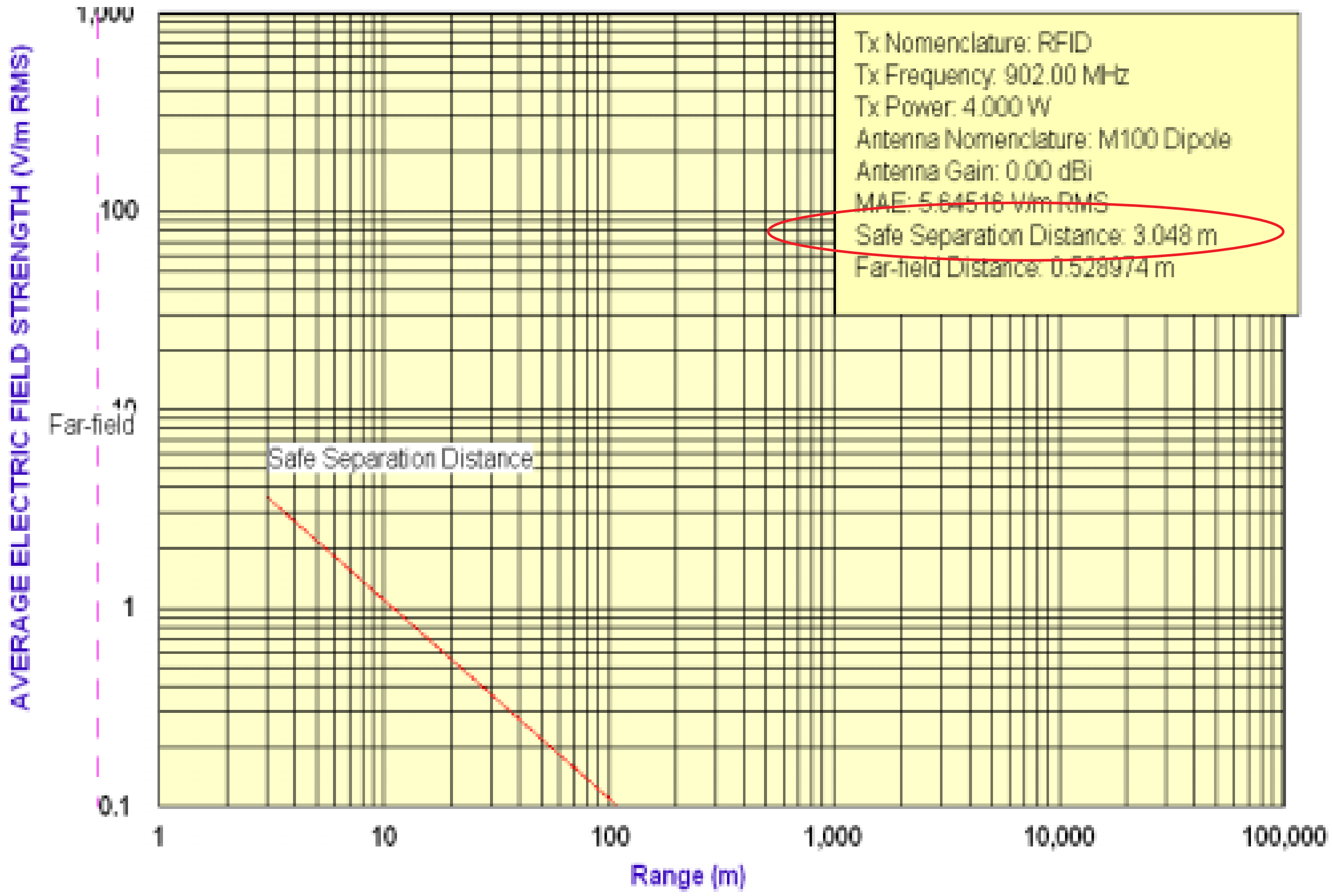
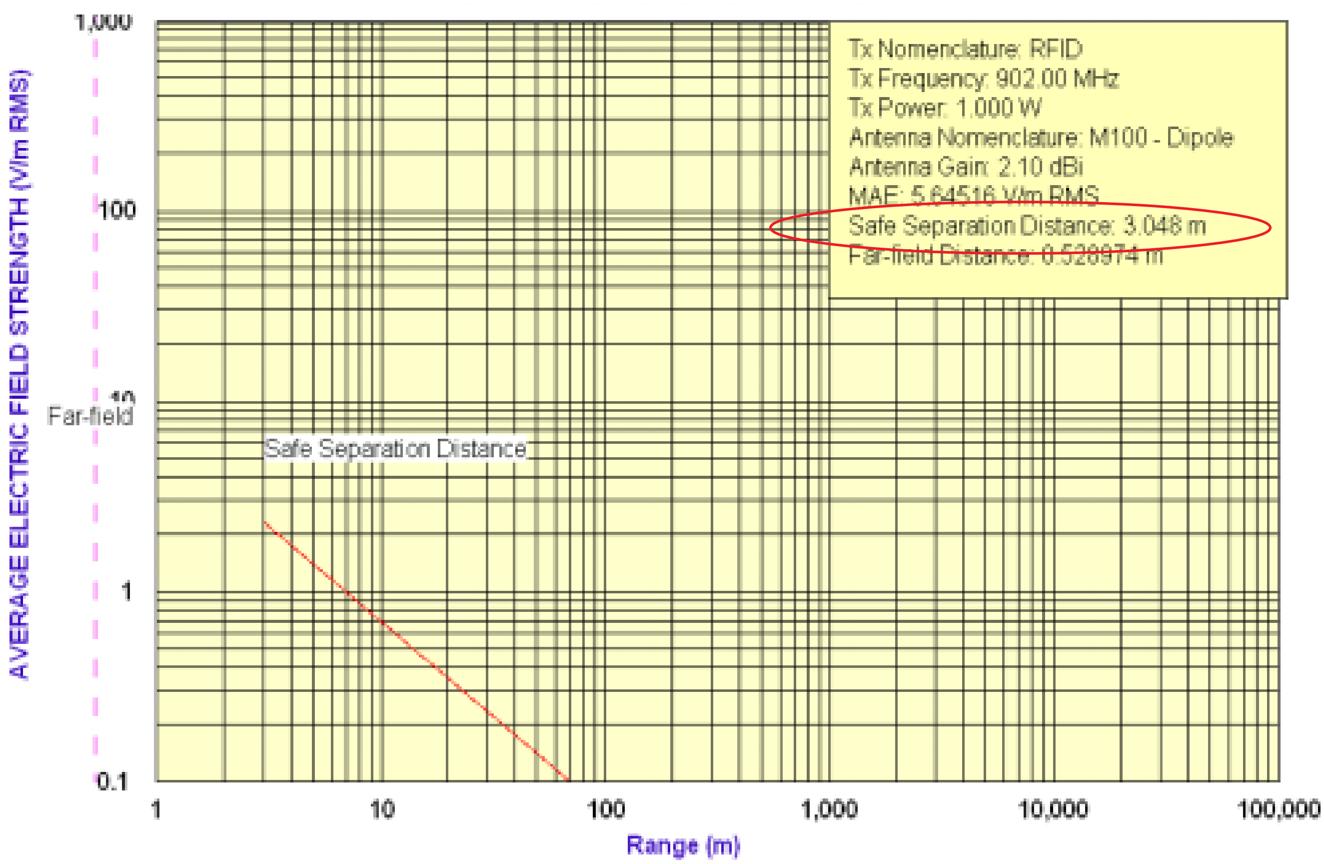
Relative Size Of Bare M100 Micro Detonators



The M100 in its shipping configuration with shorting clip. These devices are always inside munition items and they are never utilized in their bare configuration. Only the M6 blasting cap is utilized in its bare configuration.

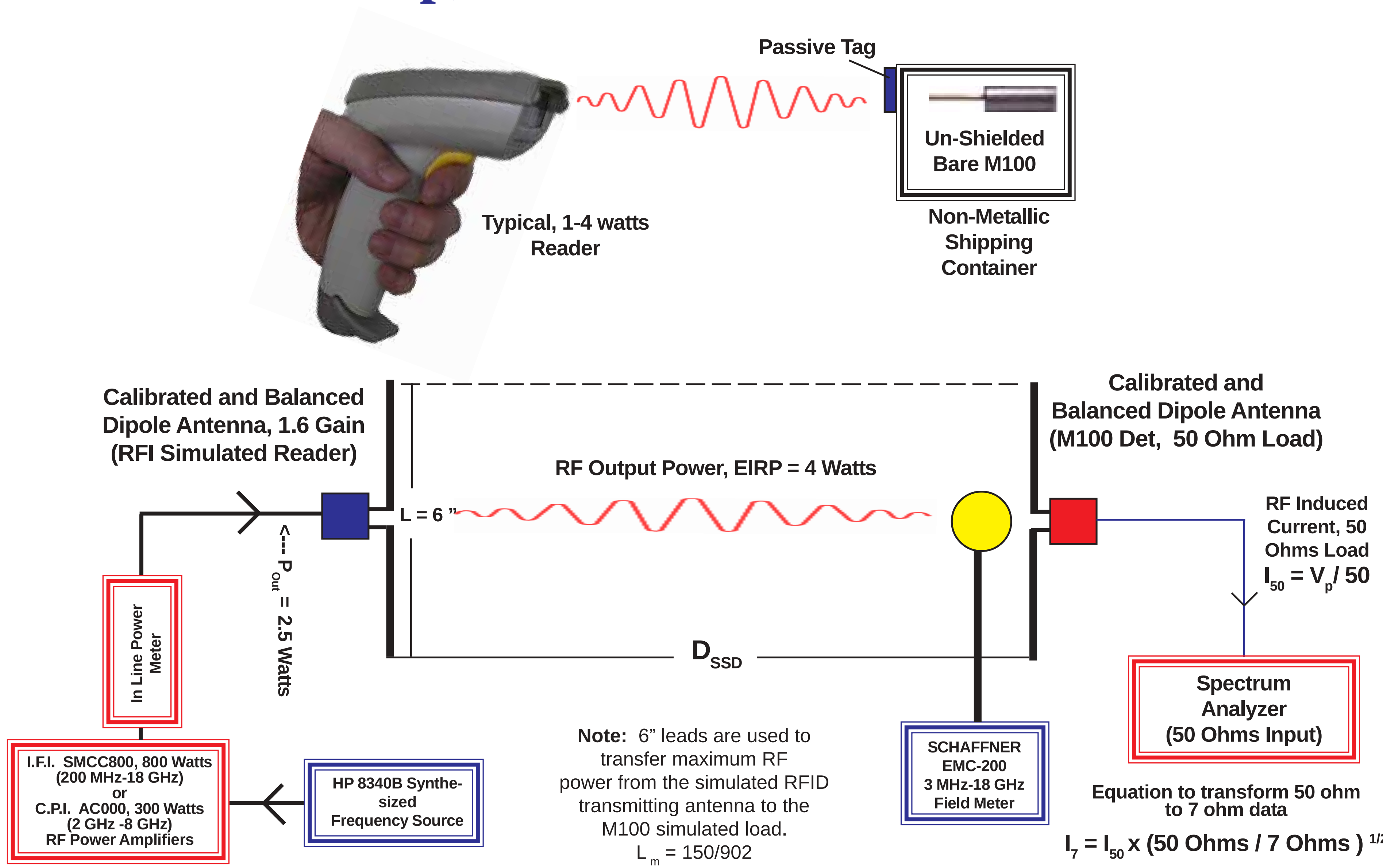
MAE Program SSD for 4 Watt Fixed Reader and 1 Watt Hand Held Reader





Enclosure 2

7 Ohm RF Induced Current Measurements, Set-Up, as a Function of Distance

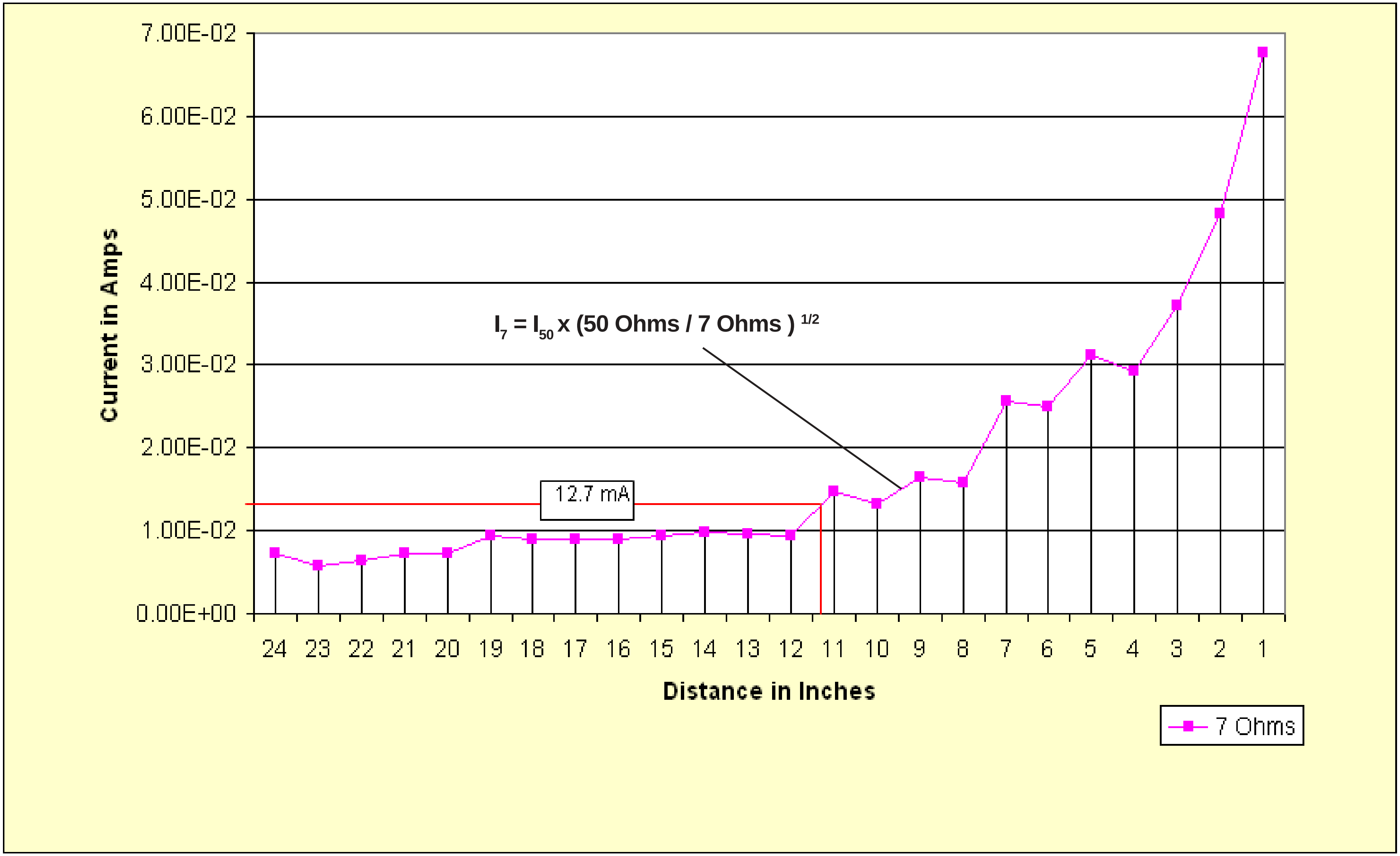


Note: 6” leads are used to transfer maximum RF power from the simulated RFID transmitting antenna to the M100 simulated load.
$L_m = 150/902$

Equation to transform 50 ohm to 7 ohm data

$$I_7 = I_{50} \times (50 \text{ Ohms} / 7 \text{ Ohms})^{1/2}$$

7 Ohm RF Induced Current Measurements as a Function of Distance



Enclosure 3b

SSD HERO Evaluations - Safety Factors

During the MAE calculations or HERO measurements, the following factors were implemented:

(a) Mandated 16.5 dB safety factor
per MIL-STD-464a....................................... 7:1

(b) NFC instead of AFC was used
for both evaluations.....................................2:1

(c) Both evaluations were performed
on a bare EED, where minimum
shielding is 30 dBs, per PAM 385-64......... 30:1

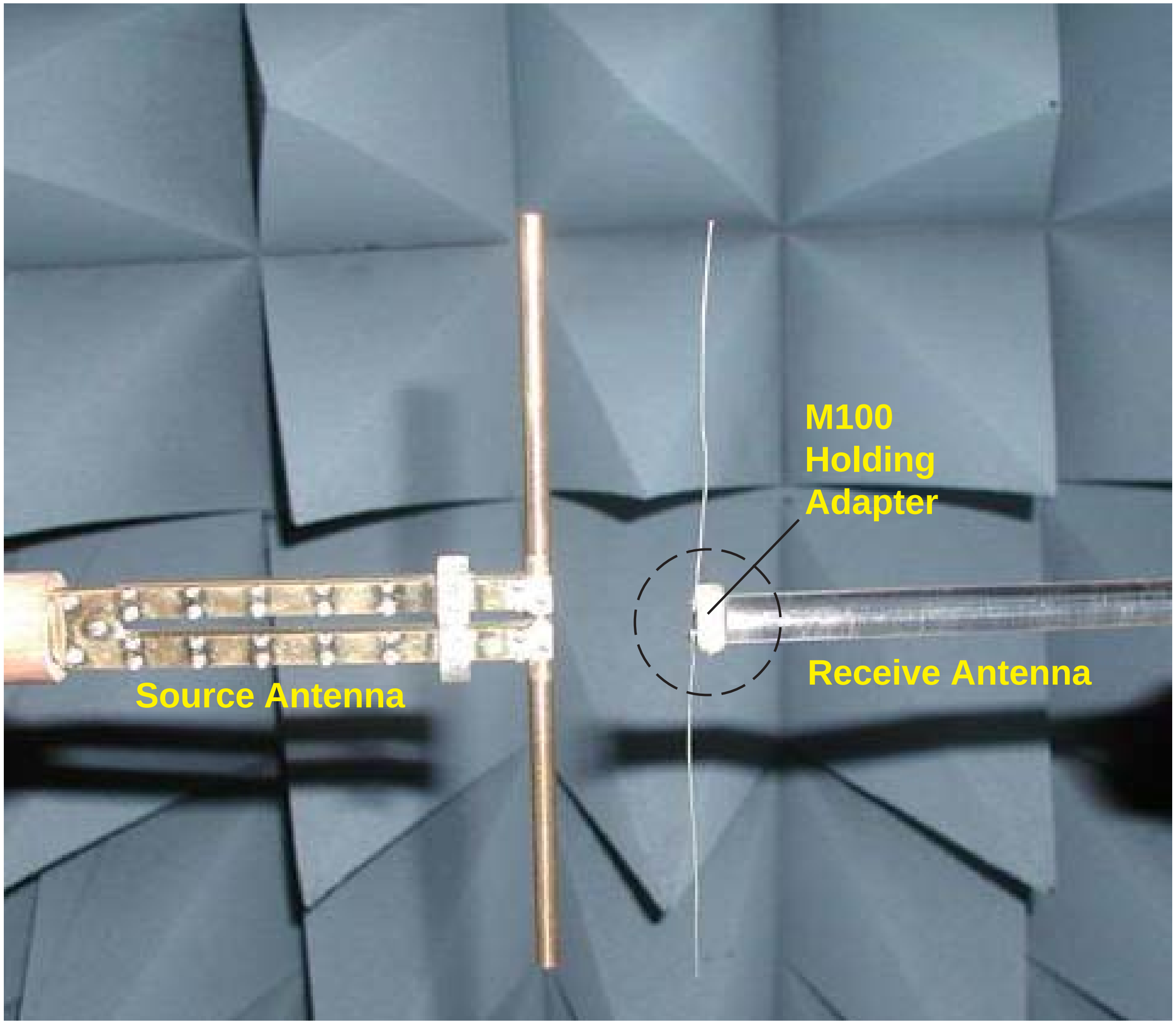
(c) According to OSU's evaluations,
the M100's resonance frequency is
7 GHz, instead of 902 Mhz, which
translates to a safetyfactor of 7:1

Total of 2940:1

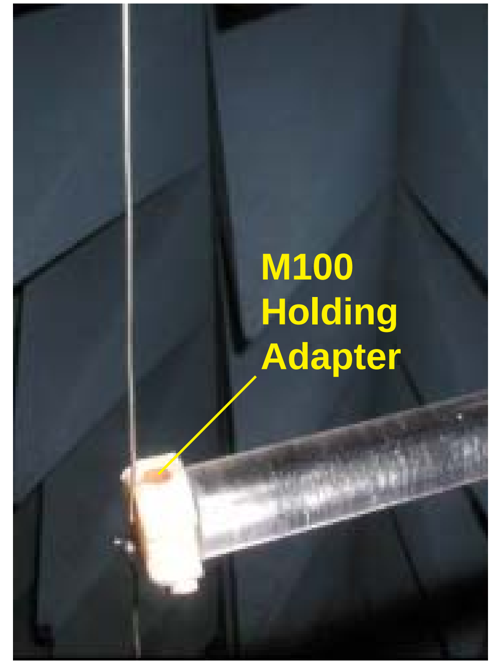
(d) Other safety factors that are hard to account for:

- Both evaluations were performed by facing the reader's antenna and the M100's antenna in front of each other and vertically polarized for maximum pick up.
- Most EEDs are not electrically connected to anything, so they don't form a dipole configuration.
- Most EEDs are protected by a shorting clip.
- All modern munition items that contain EEDs are shipped inside metal containers.
- RFID Tags are not going to be installed on the surface of the weapon system.
- Most EEDs are out of line with the HE.

M100 Detonator - Live Fire Rf Test Set-up



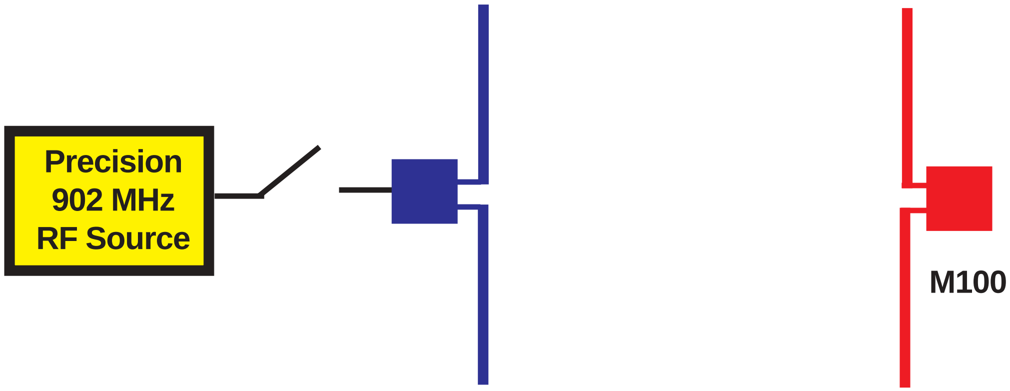
20 each live M100 Micro-Dets were subjected from 2.5 to 4 watts of RF as a function of distance.



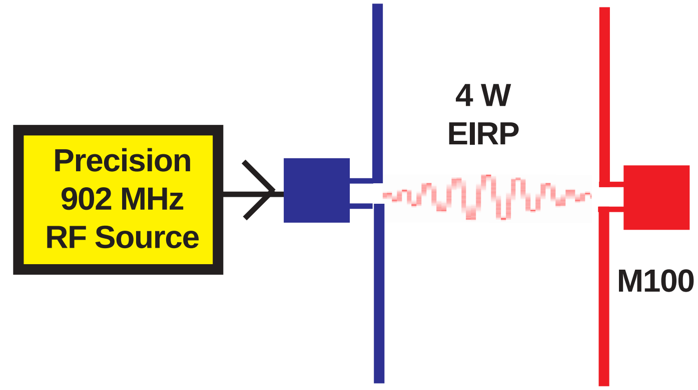
The M100 Dets were loaded into an artillery Fuze S&A adapter for safe loading and unloading of the devices. Two leads were soldered to form a dipole antenna tuned to 902 MHz.

Enclosure 5b

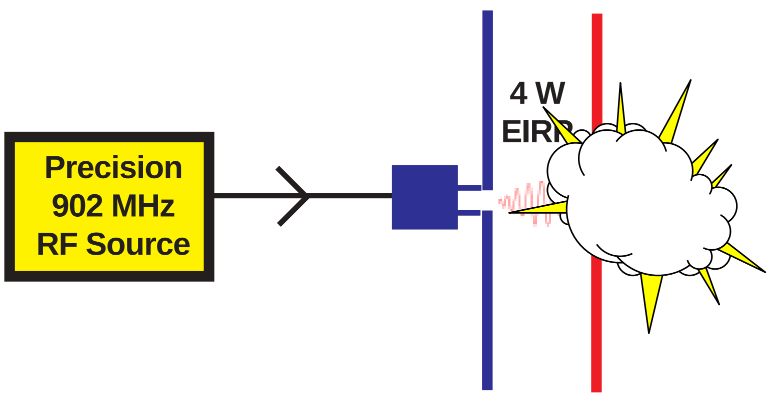
M100 Live Fire Procedures



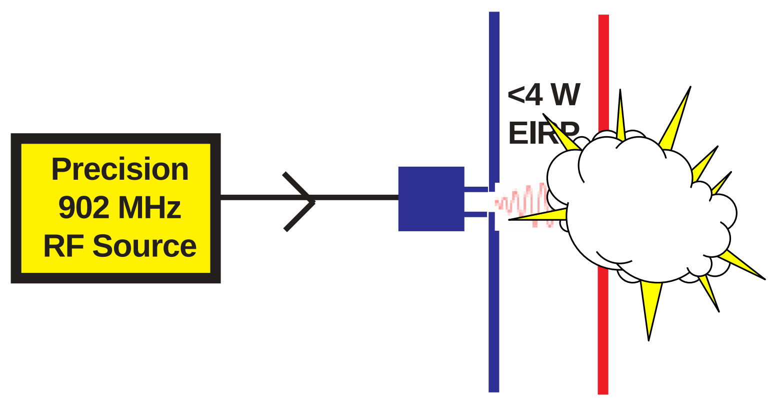
Step 1: Place both antennas 2 feet away.



Step 2: Allow source antenna to radiate and at the same time, reduce the distance between the antennas by a 1 inch increments.



Step 3: As detonation is achieved, distance was recorded.



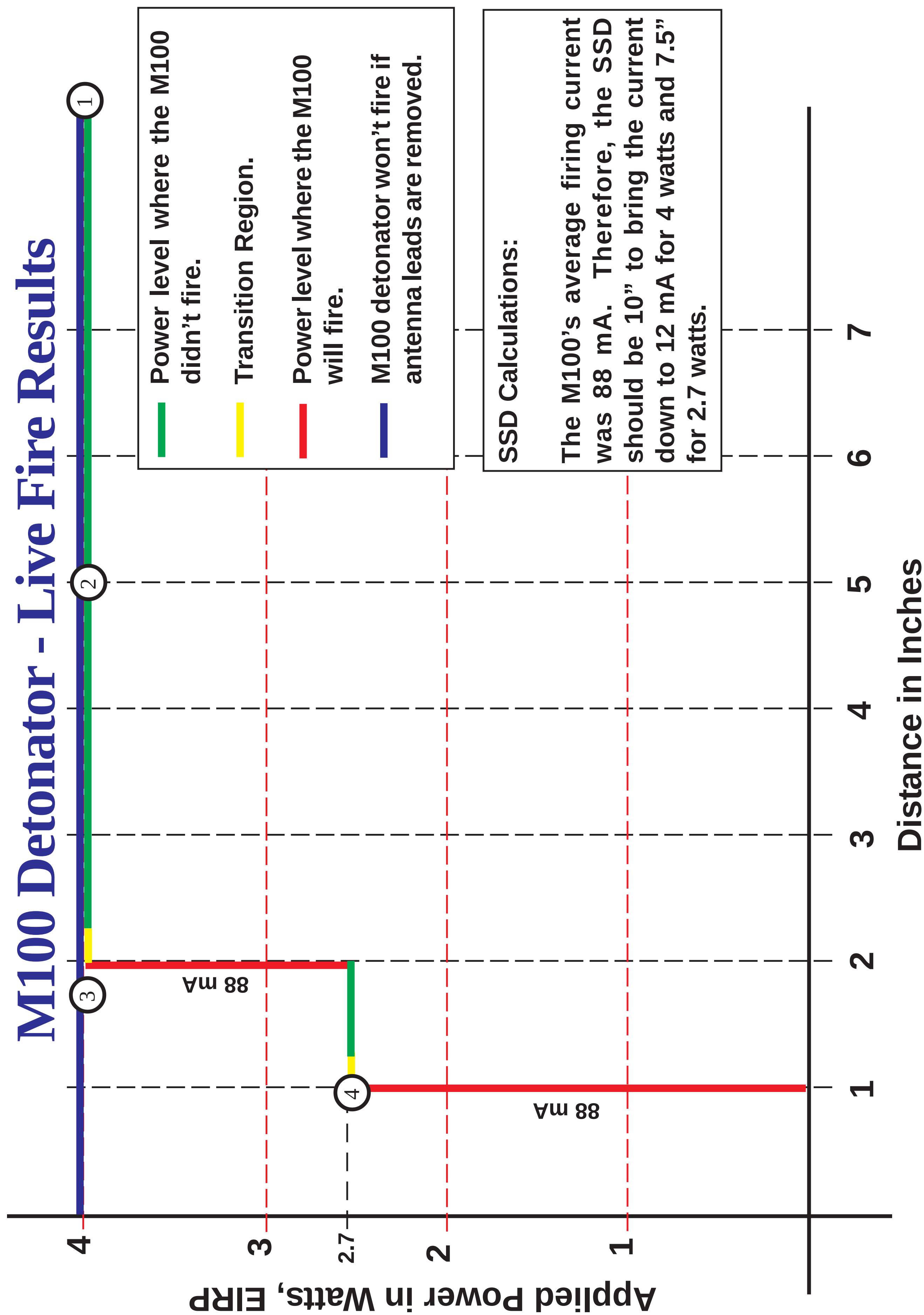
Step 4: Repeat steps 1,2 and 3 but with lower EIRP and record threshold distance.

Note: A lot of trial an error was experienced, until the process was fine tuned to minimize excessive RF exposure of the M100.

M100 Progressive Detonator Test

Detonator	Resistance in Ohms	Power in mWatts	Bridgewire dc Current in mA																				
#	R bw	R bw	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	Sub Total
1	5.1	36.8										1	0										85
2	5.2	42.1										0	1										90
3	5.4	43.7										0	1										90
4	5.3	38.3										1	0										85
5	5.5	44.6										0	1										90
6	5.4	39.0										1	0										85
7	5.7	46.2										0	1										90
8	5.4	39.0										1	0										85
9	5.3	42.9										0	1										90
10	5.5	44.6										0	1										90
11	5.4	43.7										0	1										90
12	5.6	40.5										1	0										85
13	5.4	43.7										0	1										90
14	5.3	38.3										1	0										85
15	5.5	44.6										0	1										90
16	5.4	43.7										0	1										90
17	5.1	41.3										0	1										90
18	5.4	39.0										1	0										85
19	5.3	42.9										0	1										90
20	5.5	39.7										1	0										85
21	5.6	45.4										0	1										90
22	5.4	43.7										0	1										90
Average	5.4	42.0	Average Current = 88.18 mA																				

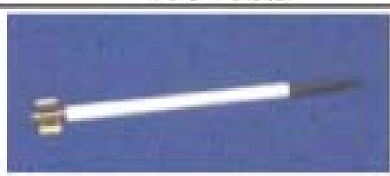
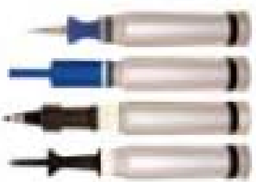
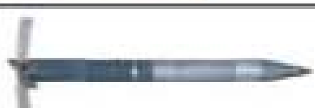
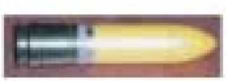
Enclosure 5c



Enclosure 5d

Enclosure 6

HERO Issues to Address on Army Legacy Ammo

Name of Item	Status of Item(s)	Corrective Action
  M21 Main Gun Pyrotechnic Simulator	The M21 family of pyrotechnics are susceptible to RF and ESD.	 The M30 and M31A1 pyrotechnic devices have replaced M21 the M21 has been discontinued. The M21 will be fired with 1 amp / 1 watt electric matches. *No issues at 902 MHz.*
 2.75" Rocket Motor, Mod 1, 2 & 3	Mods 1, 2 and 3 utilize HERO susceptible rocket motor squibs.	The E3 certified Mod 4 will replace all Mods. *No issues at 902 MHz.*
 105mm and 120mm Tank Ammo	All electric primers are susceptible to RF, only when electrode is touched.	 All tank rounds are shipped and stored inside steel containers. All electric primers will be modified with SCB technology or 1 amp/ 1 watt technology. *No issues at 902 MHz.*
 M6 Blasting Cap	M6 is susceptible to RF.	 In the future, M6s will be detonated by lasers. The M6 is shipped and stored inside aluminum barrier bags. *No issues at 902 MHz.*
 M55 Chemical Rocket	The M55 rocket squib is extremely susceptible against RF and ESD.	The M55 rockets are not being shipped, rather they are being demiled. *No issues at 902 MHz.*
 M61A1 20mm and 30mm Rounds	These rounds are highly susceptible to RF and ESD, only when electrode is touched.	 These rounds must be kept inside ammo cans and in he future they may be fired laser technology. *No issues at 902 MHz.*

Army Hero Certified Fielded Items With M100 Detonators

ARTILLERY FUZES

NOMENCLATURES:

1. M762 Time/PD
2. M767 Time/PD
3. M732 Prox
4. M783 Prox/Time

MORTAR FUZES

NOMENCLATURES:

1. M734 PD/Prox

DEMOLITION SYSTEMS

NOMENCLATURES:

1. TDFD

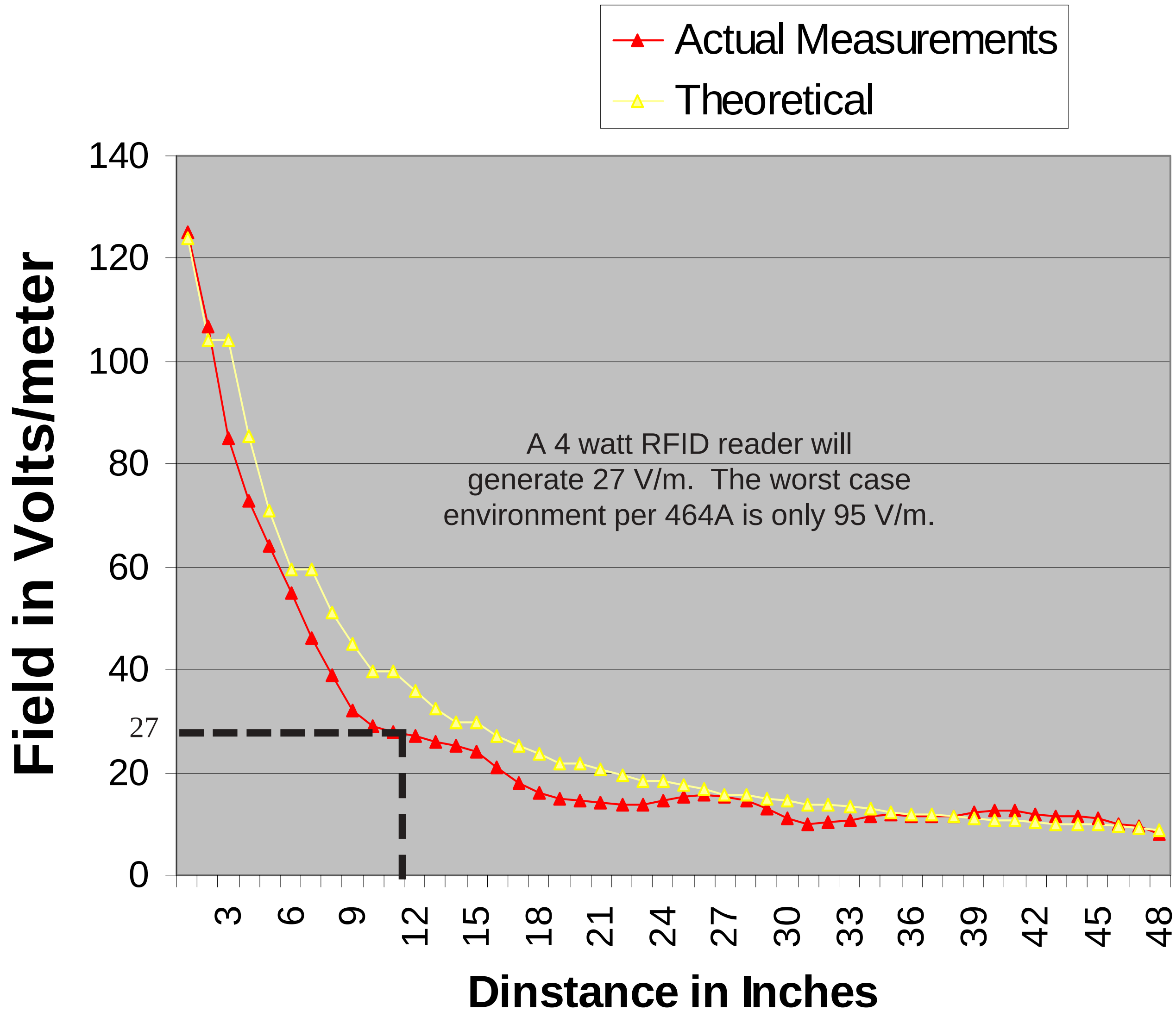
MINE FUZES

NOMENCLATURES:

1. GATOR (BLU 91/B AT & BLU 92/B AP)
2. M87-VOLCANO (BLU 91/B AT & BLU 92/B AP)
3. ADAM (M692 AP & M731 AP)
4. GEMSS (M75 AT & BM74 AP)
5. RAAMS (M718 AT & M741 AT)

Enclosure 8

Near Field Electromagnetic Fields as a Function of Distance



MIL-STD-464A HERO Table, Worst Case Environment

Frequency in MHz	Fiel Intensity in V/m	ERP in Watts
0.01 - 2	70	367
2 - 30	200	2998
30 - 150	61	279
150 - 225	61	279
225 - 400	70	367
400 - 700	260	5067
700 - 1000	**95**	**677**
1000 - 2000	410	12601
2000 - 2700	460	15862
2700 - 3600	490	17998
3600 - 4000	2620	514557
4000 - 5400	310	7204
5400 - 5900	300	6746
5900 - 6000	300	6746
6000 - 7900	320	7676
7900 - 8000	390	11401
8000 - 8400	860	55441
8400 - 8500	390	11401
8500 - 11000	1760	232197
11000 - 14000	390	11401
14000 - 18000	350	9183
18000 - 40000	420	13223
40000 - 45000	670	33650